UNITED
NATIONS

A

General Assembly

Distr.
GENERAL

A/AC.105/440
9 January 1990

ORIGINAL: ENGLISH

COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

REPORT ON THE UNITED NATIONS INTERNATIONAL TRAINING COURSE ON THE USE OF REMOTE SENSING DATA IN AGRICULTURE MANAGEMENT, HELD IN CO-OPERATION WITH THE GOVERNMENT OF THE UNION OF SOVIET SOCIALIST REPUBLICS

(Moscow, 25 September-6 October 1989)

CONTENTS

		Paragraphs	Page
INTRODUCTION		1 - 14	2
A.	Background and objectives	1 - 6	2
B.	Organization and programme	7 - 14	3
I.	SUMMARY OF THE COURSE	15 - 42	4
A.	Aerial point sampling for land use surveys	15 - 29	4
B.	Evaluation of agro-ecosystems by remote sensing	30 - 32	6
C.	Use of the Advanced Very High Resolution Radiometer of the National Oceanic and Atmospheric Administration for the monitoring of vegetation	33 - 37	7
D.	Satellite remote sensing of biomass production in the Sahel	38 - 42	8
II.	COURSE EVALUATION	43 - 44	9

Annexes

I.	List of participants and invited lecturers	10
II.	Programme of the course	11

INTRODUCTION

A. Background and objectives

1. At its thirty-seventh session, the General Assembly adopted resolution 37/90 of 10 December 1982, in which it endorsed the recommendation of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should promote the growth of indigenous nuclei and an autonomous technological base in space technology.

2. At its thirty-first session, in June 1988, the Committee on the Peaceful Uses of Outer Space endorsed the activities of the United Nations Programme on Space Applications for 1989 as proposed by the Expert on Space Applications and as recommended by its Scientific and Technical Sub-Committee at its twenty-fifth session. Subsequently, the General Assembly, at its forty-third session, endorsed the activities of the Programme for 1989 (resolution 43/56 of 6 December 1988).

3. The United Nations International Training Course on the Use of Remote Sensing Data in Agriculture Management, organized in co-operation with the Government of the Union of Soviet Socialist Republics, was one of the activities of the Programme for 1989. The training course was hosted by the USSR State Committee for Science and Technology and the Scientific and Research Centre "AIUS-Agro-resources",* and was held in Moscow from 25 September to 6 October 1989.

4. The objective of the course was to provide education and practical training to participants from developing countries with respect to the results of recent applications of air- and space-borne remote sensing techniques to the management of agriculture. Other aspects covered by the training course included an overview of different sensor systems, airborne and satellite platforms; an introduction to image analysis techniques; interpretation of remote sensing data; use of vegetation index in the monitoring of the environment; and use of geographic information systems for management in agriculture and related subjects.

5. The present report, which covers the background, objectives and organization of the training course as well as a summary of the presentations, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Sub-Committee. Participants shall report to appropriate authorities in their respective countries.

6. The participants expressed their appreciation to the United Nations and the Government of the USSR for organizing and hosting the course, for their financial assistance and for the technical quality of the course.

---

* AIUS-Agroresources = Automated Information and Management System in Agriculture.

B. Organization and programme

7. Participants in the course were from 16 developing countries: Algeria, Argentina, China, Cuba, India, Indonesia, Iraq, Kuwait, Laos, Mexico, Sri Lanka, Syrian Arab Republic, Thailand, United Arab Emirates, Viet Nam and Democratic Yemen.

8. Representatives of the following national and international organizations took part in the training course as invited lecturers: European Space Agency (ESA), United Nations Environment Programme (UNEP), Food and Agriculture Organization of the United Nations (FAO), State Commission for Science and Technology of China and National Aeronautics and Space Administration (NASA) of the United States of America. A list of participants and invited lecturers is included in annex I to the present report.

9. Funds allocated by the United Nations were used to defray the cost of international air travel of all the participants as well as a partial daily subsistence allowance for the duration of the course. The Government of the USSR provided room and board for all the participants. The agencies mentioned in paragraph 8 above sponsored their representatives as lecturers for the course.

10. The programme of the course was designed jointly by the United Nations, the State Committee for Science and Technology of the USSR and the AIUS-Agroresources Centre. The United Nations was responsible for the overall external organizational arrangements and the Government of the USSR, through its State Committee for Science and Technology, co-ordinated the local arrangements and provided technical equipment, materials, course facilities and local transportation. The programme of the course is shown in annex II to the present report.

11. The course was opened by General P. Popovitch, Director of the AIUS-Agroresources Centre, on behalf of the Government of the USSR, and the welcoming address was presented by Mr. A. Abiodun, United Nations Expert on Space Applications, on behalf of the United Nations. A welcoming statement was also made by Mr. A. Bogdanov, representative of the State Committee for Science and Technology of the USSR.

12. The presentations focused on the fundamentals of remote sensing, including principles of construction of remote sensing systems; characteristics of aerial and space platforms; the principles of camera, scanner and radar systems; image interpretation and analysis; and the characteristics of photographic and digital images. Instruction was also provided on different aspects of agricultural applications of remote sensing methods (see paras. 15-42 below) including the use of vegetation indices in environmental monitoring; methods of classification and cluster analyses of vegetation; estimation of crop condition and productivity; aerial point sampling for agricultural and land-use survey; and techniques of aerial survey in agro-resources monitoring. Many workshops and practical exercises were also organized in order to illustrate these applications.

13. A number of the participants and invited lecturers made presentations on projects/programmes in which they were involved in their own countries. These presentations included the development of remote sensing techniques for

agricultural applications in China; mapping of natural resources (water, land use, forestry, fishery, agriculture) and ecological monitoring in Thailand; experiences of the Space Applications Centre (Indian Space Research Organization) in the applications of remote sensing in agriculture; and the present status and future development of the Indian Remote Sensing (IRS) satellites series.

14. Numerous practical exercises were organized in order to provide the participants with the opportunity for "hands-on" training in the interpretation of aerial photographs, automated data processing and methods of classification and cluster analyses of images. The course was supplemented by an on-site familiarization visit to an airborne remote sensing system on board a special-purpose TU-134-SH aeroplane.

I. SUMMARY OF THE COURSE

A. Aerial point sampling for land use surveys

15. Conventional large-format photography suffers from two main drawbacks. First, its high costs prohibit its use on a sufficiently large scale to resolve the problem posed by intricate patterns of smallholder land use. Secondly, the climatic "window" during which high-altitude photography can be carried out, especially in East Africa, rarely coincides with the stage of maximum crop differentiation and usually coincides with the post-harvest period.

16. Satellite systems, which are considered to be useful tools for smallholder land use monitoring and mensuration, suffer from the same drawbacks. Imaging conditions are often poorest at the times most suitable for surveys, while even the 10-metre resolution of SPOT is still inadequate to identify some of the intricacies of the landscape. For example, in Kenya, the median field size for all cereal crops is 0.2 hectares; this requires a resolution approaching 2 metres.

17. The aerial point sampling (APS) method overcomes these problems in two ways: (a) since flight is relatively low (between 400 and 1,200 feet above ground) weather conditions, even heavy rain, rarely interrupt the flying schedule; (b) very large scale colour photography is used.

18. The equipment requirements for an APS sample are modest compared to more conventional photography. Minimum requirements are for a light aircraft with a vertically mounted 35-mm camera with a bulk back and a radar altimeter for monitoring height above ground level. Colour diapositive film, which can be developed commercially virtually anywhere within 24 hours, is used. A Cessna 206 aircraft with twin vertical bulk-backed 35-mm Nikon F3 cameras, a radar altimeter and an OMEGA/VLF navigation system were used for a study conducted in Kenya.

19. Aerial point sampling is a three-level system of flight lines, vertical point sample photographs taken at intervals along the lines and sample estimates of land cover taken from the photographs.

READEX FICHE

20. The primary sample intensity is determined by the median size of the smallest set of reporting units. In Kenya, these units usually average around 200-300 km^2. The flight lines are spaced 2.5 km apart, and the point sample photographs are taken at 1-km intervals along each flight line.

21. The vertical point sample photographs are taken on high-speed colour diapositive film. The flying height and focal length of the lens are selected to give a nominal image scale of 1:7,000 and a ground coverage of 4.2 ha. The exact height of the aircraft is recorded each time a photograph is taken, so that the exact scale can be calculated later. At this nominal scale, each photograph covers about 4.2 ha, and on the average, one sample photograph covers an area of 2.5 km^2.

22. Each photograph is treated as a point sample, and fixing their precise location is essential to the whole APS method. Every time a photograph is taken, the distance along the flight line from the starting point as well as the distance to the left or the right of the track, are recorded by the OMEGA/VLF navigation system. From these two parameters it is possible to plot the locations of each sample photograph on a map overlay to within 200-300 m.

23. Typically, a 1:250,000 scale map overlay is made showing the position of each of the sample photographs. The overlay is then used to assign each point sample to any stratum, such as a district, division or location; catchment or sub-catchment; soil type; or climate zone. This is done by placing the overlay on the appropriate 1:250,000 scale base map of the stratum boundaries.

24. Once a sample point has been assigned to a stratum such as a location or a soil type, it can be associated with any characteristic of that stratum such as population density or inherent erodibility. The APS method thus provides a powerful tool for integrating a wide range of ancillary data into a land use survey.

25. All data associated with the sample points can then be used to create statistical estimates for the different strata, for example for each district, division and location within the survey area.

26. For purposes of interpretation, each colour diapositive is projected onto a desk-top dot grid, at an enlargement of x 10, in order to give an average interpretation scale of 1:700. The semi-random dot grids consist of an array of 18 x 12 cells of 2 x 2 cm in size; in each of these are two randomly located dots of approximately 1.5 mm diameter, equivalent to 1.05 m on the ground at the average interpretation scale. The photo-interpretation is carried out only within an inner interpretation area of 16 x 10 = 160 cells containing 320 dots.

27. One of the most important features of the APS method is the flexibility with which data can be integrated within a spatial context. As described above, this is achieved by determining the spatial co-ordinates of each sample point to an accuracy of 250-300 m, which is the operational accuracy of the navigation system in the survey aircraft. Once the co-ordinates of each sample point are known, they can be related to any physical reference point located within the boundaries of any of the information strata of the study area. It is also possible to calculate the distance between each sample point and any other defined point in the survey area, such as a crop silo or a major road.

28. The APS method has evolved over the last six years in response to requirements from East Africa development planners for regional-level data on land use and land cover. The method has been widely tested. It appears to be very robust and able to deliver usable data on a wide range of land covers within a wide range of reporting units. The ability to integrate ancillary data within the photo data base is an additional advantage.

29. Generalization with regard to costs is difficult since labour, aircraft and film costs vary widely from country to country. In Kenya, a typical APS survey over 40,000 km^2, with a sample point density of one per 2.5 km^2, analysing some 200 land cover variables and 50 ancillary data variables, reporting on 12 major strata and producing some 100 coloured thematic grid cell maps, will cost approximately $US 6.00 per square kilometre. This cost can be as low as $US 2.00 per square kilometre if very few variables are analysed and as high as $US 10.00 per square kilometre if the survey results in the creation and installation of a major data base.

B. Evaluation of agro-ecosystems by remote sensing

30. Remote sensing techniques to monitor agro-ecosystems have been developed within the framework of the Automated Information and Management System in Agriculture ("AIUS-Agroresources") of the USSR. The priority tasks of this system include the classification of vegetation types and the assessment of land-surface moisture. The agro-monitoring system is based on the principles of the Geographic Information System (GIS) and includes the functions of obtaining aerospace information, carrying out ground observations, automated thematic processing of incoming digital and analog information, archiving of information and the use of data banks.

31. The above system integrates data from a number of remote sensing platforms operating at different altitudes. These include data from different multispectral scanning and photographic systems on board spacecraft and high-altitude TU-134 laboratory planes, data from spectrometers and microwave radiometers on low-flying planes as well as land-based information and data from radio-location instruments.

32. In developing the above system, primary attention was paid to the development of a vegetation index and to an accurate determination of the spatial distribution of soil moisture. The parameter of above-ground biomass was used as an indicator of the productivity of an agro-ecosystem. Values for biomass and soil moisture, along with other remote sensing data, were used as input parameters for mathematical models that were developed for the prediction of crop yields.

C. Use of the Advanced Very High Resolution Radiometer of the National Oceanic and Atmospheric Administration for the monitoring of vegetation

33. The current satellites of the United States National Oceanic and Atmospheric Administration (NOAA) carry seven different sensor systems for observing the Earth and its atmosphere, as well as two data collection/transmission systems. Of the sensor systems, the Advanced Very High Resolution Radiometer (AVHRR) has a multispectral capability similar to that of the Landsat and SPOT satellites. The AVHRR collects reflected and emitted electromagnetic radiation in five different spectral bands, one each in the visible, near-infrared and middle infrared and two in the thermal infrared.

34. With the support of the Global Inventory, Modelling and Monitoring Systems (GIMMS) Group at the NASA Goddard Space Flight Center, the FAO Remote Sensing Centre has developed and tested the use of AVHRR data for the large-scale assessment of crop conditions and range land productivity. This information, combined with Meteosat based rainfall assessments, have been used to pin-point areas in the deserts of northern Africa, the Near East and south-west Asia having suitable vegetation conditions for the development of potentially dangerous desert locust populations.

35. For this purpose, NOAA-AVHRR data are processed in vegetation index format, using the normalized difference vegetation index (NDVI), calculated from the visible (580-680 nm) and near-infrared (725-1,100 nm) bands of the AVHRR.

36. The NOAA satellites provide effective world-wide data coverage every two to three days in the form of global area coverage (GAC) data produced through on-board resampling of the primary AVHRR data acquired by the satellite at full (1.1-km) resolution to a 4-km resolution. The full-resolution data can be received directly by regional receiving stations in the form of high-resolution picture transmission (HRPT) data.

37. The relatively high temporal repeat frequency of the NOAA AVHRR data, as compared to those generated by the Landsat and SPOT satellites, allows for the detection and monitoring of green vegetation dynamics, even in seasonally frequently cloud-covered areas, by analysing data collected over 10-day periods. The technique for obtaining virtually cloud-free NOAA-AVHRR NDVI data on a 10-day basis has been successfully tested; it uses the daily available NOAA-AVHRR data in the red, near infrared and thermal infrared channels. The thermal infrared data is used to identify features in the cloud-covered areas. Data for a 10-day period is mapped to a selected geographic projection and cloud-free composite images are obtained for these periods using computer mapping of the cloud-free parts by selecting pixels with the maximum NDVI; this process minimizes the effects of atmospheric influences as dust and haze.

D. Satellite remote sensing of biomass production in the Sahel

38. Primary production of grasses in the Sahel and elsewhere can be determined by remote sensing techniques. Both the green leaf biomass and the intercepted photosynthetically active radiation of plant canopies can be estimated using red and near-infrared spectral data. Primary production can also be spectrally estimated by integrating frequently collected red and near-infrared responses over the growing season. These estimates result from high correlation between the various "greenness" indices and the absorbed or intercepted photosynthetically active radiation and the relationship of this integral to primary production and yield.

39. The FAO/UNEP Pastoral Ecosystems Project in the 30,000-km^2 Ferlo area of the Sahel of Senegal has provided an opportunity to investigate satellite remote sensing of Sahelian herbaceous biomass production. Ground-based biomass sampling by the project began in 1980 and continued through 1984. Inspection of the available Landsat data corresponding to 1980-1984 for the Sahel zone of Senegal and adjacent areas indicated that the data could not be used to determine the multitemporal greenness of the area because there were insufficient Landsat observations to form a multitemporal data set for any year. Thus the NOAA-AVHRR data were used. The AVHRR local area coverage (LAC) data (pixel size, 1.1 km) are well suited for a Sahelian setting like the Ferlo area where the smallest unit of primary production occurs in dune and inter-dune areas which are 1 to 2 km wide. AVHRR GAC data (pixel size, 4 km) were also used when LAC data were not available. The AVHRR sensor offers high temporal resolving power, acquiring useful satellite data over a given area several times during every nine-day orbital cycle.

40. All of the AVHRR data were mapped to a Mercator's projection, registered interactively using the coastline for reference, and the normalized difference vegetation index was calculated. Maximum registration errors were 2-3 km for the LAC data and 4-6 km for the GAC data, and average errors were 1-2 km after interactive registration.

41. Extensive field data collection was conducted in the Ferlo area during and at the conclusion of the 1980-1983 rainy seasons. No field data collection was done in 1984 because of the extreme drought. Three-band, hand-held radiometer measurements, clipped samples, visual estimates and visual observations were made in 1981, 1982, and 1983. Only clipped samples and visual estimates were made in 1980. A total of 68 locations, each 6-10 m^2 in size, were clipped, and numerous visual estimates were made. Before clipping, the dominant and next dominant species were noted, the percentage cover was estimated and the mean grass height measured.

42. The synoptic nature of observations from satellite altitudes is an advantage for estimating primary production since large areas can be measured directly; the green-leaf biomass also integrates many abiotic and biotic variables which directly affect primary production. Whether precipitation and/or nutrients are the limiting factors, the green-leaf biomass should be capable of reflecting these limiting conditions. Consequently, what is needed are frequently collected satellite data and a number of ground samples which can be used to establish the validity of the

technique. When validated, these ground samples can provide the calibration relationships for extrapolation throughout the satellite-measured area.

II. COURSE EVALUATION

43. At the conclusion of the course, the participants were asked to complete a questionnaire regarding various aspects of the contents and organization of the course, the time alloted to the topics and practical exercises as well as the relevance of the course content to their day-to-day activities. This exercise was followed by a round-table discussion of the potential and limitations of remote sensing applications for agriculture and environmental monitoring. During the discussions, the participants made a number of comments related to the accomplishments of the course and recommendations for future courses.

44. Most of the participants expressed the opinion that the general organization and the planning of the presentations were of high quality. Depending on their experience and field of expertise, some participants felt that more time should have been spent on the practical exercises that were of interest to them. Finally, the majority of the participants indicated that the level and content of the training course were appropriate for the specific needs of their work. The participants expressed their appreciation to the Government of the USSR and to the United Nations for having organized the training course.

Annex I

LIST OF PARTICIPANTS AND INVITED LECTURERS

Participants

Mr. Ahmed Abdul Rahman Al-Masoum	United Arab Emirates
Mr. Khaled Abdul Aziz Al-Sharaa	Syrian Arab Republic
Mr. Yousuf Mohammed Ali Al-Tarakma	Kuwait
Ms. Miriam Esther Antes	Argentina
Mr. Iskander Abdul Karim Bazara	Democratic Yemen
Mr. Jorge Enrique Brena-Zepeda	Mexico
Mr. Sunil Dimantha	Sri Lanka
Mr. Nabeel Toma Hendow	Iraq
Ms. Huiping Liu	China
Mr. Manu Omakupt	Thailand
Mr. Luis Carlos Ortega Blanco	Cuba
Mr. Narayana Swamy Ravi	India
Mr. Hardjito Saroso	Indonesia
Mr. Said Serradj	Algeria
Mr. Vayaphat Thattamanivong	Laos
Mr. Ruyen Dinh Truong	Viet Nam

Invited lecturers from outside the Soviet Union

Dr. Michael Norton-Griffiths, UNEP, Kenya

Dr. Jelle U. Hielkema, FAO, Italy

Dr. Luigi Fusco, ESA, Italy

Dr. Wu Guoxiang, State Commission for Science and Technology, China

Dr. C. J. Tucker, NASA, United States

Annex II

PROGRAMME OF THE COURSE

Date	Time	Subject	Lecturer
Monday 25 Sept.	10-10.30 a.m.	Registration of participants	
	10.30-11.15 a.m.	Opening ceremony	Gen. Popovitch P., Director of AIUS-Agroresources Centre A. A. Abiodun, United Nations A. Bogdanov, USSR State Committee for Science and Technology
	11.30 a.m.-1 p.m.	Fundamentals, structure and design of cadaster-ecological monitoring	P. F. Loiko, USSR
	2.30-4 p.m.	Fundamentals of remote sensing	N. V. Sazanov, USSR
	4-5.30 p.m.	Principles of the design of the remote sensing system	
Tuesday 26 Sept.	10 a.m.-noon	Monitoring of vegetation state	J. U. Hielkema, FAO
	Noon-1 p.m.	Physical, landscape and indication features of the agro-monitoring objects	B. N. Rodionov, USSR
	6 p.m.	Reception organized by the State Committee for Science and Technology and AIUS-Agroresources Centre	
Wednesday 27 Sept.	10 a.m.-noon	On-board aerial and space remote sensing complexes	G. N. Barishev, USSR
	Noon-1 p.m.	Techniques of aerial surveying in the system of agroresources monitoring	U. N. Dedaev, USSR

/...

Date	Time	Subject	Lecturer
Wednesday 27 Sept. (cont.)	2.30-6 p.m.	Acquaintance with the airborne remote sensing complex on board the special-purpose TU-134 SH Plane	G. A. Barishev, USSR U. N. Dedaev, USSR
Thursday 28 Sept.	10 a.m.-1 p.m.	Estimation of the crop condition and productivity based on remote sensing	N. M. Vandisheva, USSR
	2.30-4.30 p.m.	Development of remote sensing techniques for agricultural applications in China	Wu Guoxiang, China
	4.30-6 p.m.	Discussion of the reports	
Friday 29 Sept.	10-11.30 a.m.	Analog and digital methods of image processing and analyses and remote sensing data	L. Fusco, ESA
	11.30 a.m.-1 p.m.	Technology and hardware of airborne scanner data processing for agroresources in remote sensing	U. B. Skorobogatov, USSR
	2.30-6 p.m.	The algorithms of radiometric and radiation correction and automatic topical remote sensing data processing in the channels of the visible, near-IR and thermal-IR bands	A. A. Feoktistov, USSR
Saturday 30 Sept.		Cultural programme	Organizing Committee
Sunday 1 Oct.		Excursion around Moscow	Organizing Committee
Monday 2 Oct.	10-11.30 a.m.	Use of the vegetation index in environmental monitoring	C. J. Tucker, NASA
	11.30 a.m.-1 p.m.	Methods of classification and cluster analyses of vegetation canopy images	A. V. Maslov, USSR
	1-2.30 p.m.	Lunch	

/...

Date	Time	Subject	Lecturer
Monday 2 Oct. (cont.)	2.30-6 p.m.	Practical exercises related to the lecture	A. M. Chizhevski, USSR A. V. Maslov, USSR
Tuesday 3 Oct.	10-11.30 a.m.	Ground-based complexes of the remote sensing hardware	B. I. Vasilenko, USSR
	11.30 a.m.-1 p.m.	Methods of classification and cluster analyses of vegetation canopy images	A. M. Chizhevski, USSR
	2.30-3.30 p.m.	Practical exercises related to the lecture	A. M. Chizhevski, USSR
	3.30-5.30 p.m.	Hybrid optico-digital methods of image processing	G. I. Vasilenko, USSR
Wednesday 4 Oct.	10 a.m.-1 p.m.	Visit to the Centre of Cosmonauts Training at the Star City	Organizing Committee
	2.30-6 p.m.	"Solar" and "pericolor" hardware facilities for automated data processing in the AIUS-Agroresources system	S. N. Shibalov, USSR
Thursday 5 Oct.	10-11.30 a.m.	Aerial point sampling for agricultural and land-use survey	M. Norton-Griffiths, UNEP
	11.30 a.m.-1 p.m.	Prospects for the development of remote sensing systems	N. V. Sazonov, USSR
	2.30-4.30 p.m.	Prospects for the development of remote sensing systems	P. F. Loiko, USSR
	4.30-6 p.m.	Closing ceremony	Gen. P. Popovich, USSR S. Chernikov, United Nations G. I. Vasilenko, USSR
Friday 6 Oct.	10 a.m.-1 p.m.	Round-table for participants of the course (discussions and assessments of the course, presentations of participants on their national remote sensing programmes)	G. Vasilenko, USSR N. Sazonov, USSR N. Vandisheva, USSR S. Chernikov, United Nations

---

UNITED
NATIONS

A

General Assembly

Distr.
GENERAL

A/AC.105/441
12 January 1990

ORIGINAL: ENGLISH

COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

REPORT ON THE SECOND UNITED NATIONS INTERNATIONAL TRAINING COURSE ON REMOTE-SENSING APPLICATIONS TO GEOLOGICAL SCIENCES, HOSTED AND CO-SPONSORED BY THE GOVERNMENT OF THE GERMAN DEMOCRATIC REPUBLIC

(Potsdam, German Democratic Republic, 5-22 October 1989)

CONTENTS

		Paragraphs	Page
INTRODUCTION		1 - 12	3
A.	Background and purpose of the course	1 - 5	3
B.	Organization of the course	6 - 12	3
I.	SUMMARY OF THE COURSE	13 - 38	4
A.	Introduction to remote-sensing interpretation for geology and tectonics	13 - 21	4
B.	Fundamentals of remote sensing, including sensor systems	22 - 25	6
C.	Analog and digital image processing and photo-interpretation	26 - 30	7
D.	Spectral response of surface objects in the visible, infrared and microwave range	31 - 38	8
E.	Problem-oriented interpretation of images for geological purposes	39 - 41	10
F.	Role of remote sensing in assessing geological hazards	42 - 45	11

CONTENTS (continued)

	Paragraphs
G. Application of remote sensing for prospection of mineral deposits	46 - 49
H. Remote-sensing applications in hydrogeology and water resources surveys	50 - 53
I. Application of remote sensing to the study of arid and semi-arid lands	54
J. Application of mathematical methods in remote sensing	55 - 57
K. Field exercises in training areas	58 - 61
II. COURSE EVALUATION	62 - 63
Annex. PROGRAMME OF THE COURSE	

Page

12

13

14

14

15

15

16

INTRODUCTION

A. Background and purpose of the course

1. During its thirty-first session, in 1988, the Committee on the Peaceful Uses of Outer Space endorsed the United Nations Programme on Space Applications for 1989 as proposed to the Scientific and Technical Sub-Committee by the United Nations Expert on Space Applications.

2. As part of the Programme on Space Applications, a second International Training Course on Remote-Sensing Applications to Geological Sciences was organized by the United Nations and hosted and co-sponsored by the Government of the German Democratic Republic. It was held at Potsdam under the auspices of the Academy of Sciences of the German Democratic Republic from 5 to 22 October 1989.

3. The objective of the training course was to provide education and practical training to participants from developing countries with respect to techniques, methods and results of recent applications of airborne and satellite remote sensing to geological sciences.

4. The present report has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Sub-Committee. Participants will report to appropriate authorities in their home countries.

5. Participants expressed their appreciation to the United Nations and to the Government of the German Democratic Republic for organizing and hosting the course, for their financial assistance and for the scientific and technical quality of the course.

B. Organizatior of the course

6. Invitations to nominate participants for the International Training Course were sent by the United Nations to developing countries. The course was attended by 19 participants from the following countries: Bangladesh, China, Democratic Yemen, Ethiopia, India, Iraq, Libyan Arab Jamahiriya, Mongolia, Nepal, Qatar, Sierra Leone, Sri Lanka, Syrian Arab Republic, Thailand and Uganda. These participants were senior technical and scientific personnel actively engaged in geology and remote sensing in their respective countries.

7. Instruction was provided by experts from Czechoslovakia, the German Democratic Republic, Italy, the Netherlands, Poland and the Union of Soviet Socialist Republics.

8. The Central Institute for Physics of the Earth of the Academy of Sciences of the German Democratic Republic co-ordinated the local arrangements and provided the technical equipment, materials, course facilities and local transportation.

9. Funds allocated by the United Nations were used to cover the cost of international air travel for 15 participants. The Government of the German Democratic Republic provided fellowships to cover subsistence and course fees for these participants. The course was also attended by three holders of the United Nations-administered fellowship for long-term study in the German Democratic Republic.

10. The training course was formally opened by the Director of the Central Institute for Physics of the Earth, Prof. E. Hurtig, by the Secretary for Space and Earth Sciences of the Academy of Sciences of the German Democratic Republic, Prof. H. Kautzleben, and by the representative of the United Nations, Mr. H. J. Haubold.

11. The course consisted of a series of integrated lectures, presentations of case studies, exercises, field trips to different geological areas in the southern and central part of the German Democratic Republic and a visit to the Application Centre of VEB Carl Zeiss Jena.

12. Presentations focused on fundamentals as well as the current status and future trends of remote sensing, including sensor systems, analog and computer-aided image processing and analysis, the applications of mathematical methods in remote sensing, geological interpretation of satellite data, radar and thermal infrared sensing for geological and geomorphological research, applications of space remote-sensing techniques for neo-tectonic studies, seismic hazard assessment, hydrological and hydrogeological surveys and studies of arid and semi-arid lands, and on remote-sensing applications for prospection of mineral deposits. The lectures were complemented by extended exercises in the classroom and by field trips into training areas in order to develop practical skills in the geological interpretation of remote-sensing data, in the collection of relevant data from ground control points and in the verification of results of remote-sensing data interpretation in the field. The main concepts, data and conclusions of the lectures, exercises and field trips are summarized in the paragraphs below. The Central Institute for Physics of the Earth of the Academy of Sciences of the German Democratic Republic published the proceedings of the course in two volumes in advance. The programme of the course, jointly developed by the United Nations and the Government of the German Democratic Republic, is contained in the annex.

I. SUMMARY OF THE COURSE

A. Introduction to remote-sensing interpretation for geology and tectonics

13. Satellite remote sensing is especially useful for applications to survey tasks which do not require too much direct ground information; in other cases, the use of airborne or ground-based observations provides more detailed information. Satellite remote sensing is well suited for geological reconnaissance surveys, especially in arid and semi-arid areas.

14. Satellite images contain integrated information on such features as vegetation, soil, rocks, land forms, drainage patterns and geologic structures. Thematic interpretation of these complex patterns of forms, shades, colours, structures, textures and their mutual relationships requires, besides some background about the physical fundamentals and peculiarities of remote-sensing data, a thorough understanding of the processes of relief formation and their dependence on climate, the relationships between relief, rock types and geologic structures, between the interaction of endogenous and exogenous Earth-shaping forces, between the scale of features and their possibly more deep-seated origin and between soils and vegetation cover. In summary, it requires well-founded interpretation models besides an appropriate level of knowledge in geological mapping, computer processing and other techniques of data processing and presentation as well as availability of independent data sources, e.g., ground control points.

15. There exists no unique complex interpretation model with which to extract from remote-sensing imagery the diverse information of interest to geologists. Analysis of soil type is very different from structural analysis. Thus image interpretation always necessitates image "filtering" by enhancing and/or undertaking a selective evaluation of image features based on spectral signatures relevant for the given survey tasks. Thus, it is first necessary to define the task properly and subsequently choose the most appropriate procedures and methods of data collection (including ground control), processing, evaluation and presentation.

16. The geological interpretation of remote-sensing data attempts to relate characteristics of the Earth's surface to sub-surface phenomena and causes. The crustal depth to which the surface interpretation might be extended downwards depends on the scale of features considered and on the method used.

17. Despite the mostly small scale of satellite remote-sensing imagery, its geological interpretation should not be restricted to a general survey but should strive to be as detailed as possible. This may be achieved by incorporating independent large-scale information into the interpretation process, such as aerial photography or side-looking airborne radar (SLAR) images, available maps and ground verification. The results of thematic information extraction should be presented in as many different topical maps as possible (drainage, land forms, land use, soil types, vegetation, rock units, lithology, photolineations). Finally, the geologist should try to determine the processes which could best explain the development of these various features and their interrelationships.

18. The endogenous forces that shape the Earth still persist - otherwise, the continents would be eroded to sea-level within a timespan of less than 15 million years. These processes lead, among others, to folding and faulting, to interaction with external forces of weathering and gravity and subsequently to erosion and redeposition. Planar and linear features related to these processes may be recognized on satellite images even if their intensity is very low. While ongoing internal geological processes normally result in broken symmetry and non-homogeneity of features, erosion and redeposition tend to homogenize.

19. Many of the relief-forming processes of the continents are connected with lineaments. The latter are frequently related to scarps or other slope effects. These morphological features as well as differences in igneous or sedimentary rock types are recognized in remote-sensing imagery only indirectly owing to differential erosion, differences in soil porosity and water saturation, differences in tone or colour or those resulting from shadowing effects (especially in SLAR imagery). Reliable and quantifiable information about material composition can be derived only under favourable circumstances, which include the availability of high-resolution spectral data collection, appropriate processing and calibration by means of ground control data.

20. In most cases, it is not possible to identify the true nature of each individual feature seen or "suspected" by an interpreter in remote-sensing images or to find its location on the ground, especially since any visual interpretation process is not free of the influences of subjectivity, background knowledge and model concepts. Therefore, generalization and sometimes statistical evaluation of feature patterns derived from remote-sensing imagery are indispensable. Geologic interpretation can go beyond the pure documentation of such features and should attempt to provide an understanding of the process. In this context, it should be noted that various rock types will react very differently when being subjected to the same type of crustal deformation. Granites, for example, will react with brittle fracturing while limestone would yield with folding.

21. Geologic features that are recognizable in remote sensing not only permit inferences with regard to current status and past processes, they also allow the interpreter to draw, with different degrees of reliability, some conclusions with regard to future geologic events such as landslides or earthquakes.

B. Fundamentals of remote sensing, including sensor systems

22. In its most general sense, remote sensing is the observation of a target (object) by means of a device (sensor) which is separated from the target by a given distance. Specifically, remote sensing of the Earth by satellites is the observation and measurement of the energy and polarization characteristics of the emitted and reflected radiation of elements of the land, ocean areas and atmosphere of the Earth in different ranges of the electromagnetic spectrum. Information obtained through such a process can be used to describe the location, nature and time variation of natural parameters, phenomena and resources of the Earth's environment as well as of man-made objects and formations.

23. However, in order to meaningfully apply remote-sensing techniques, it is necessary for the user to be thoroughly familiar with the basic physical laws which govern the interaction of electromagnetic radiation with matter. These interactions, often referred to as the spectral properties of matter, are its reflectance, absorptance and transmittance.

24. In many remote-sensing applications, the use of various types of sensors, platforms and kinds of data collected at various altitudes (including also ground sampling) becomes essential since no single remote-sensing device or type of

platform can provide the great variety of data required for complex and reliable interpretation.

25. Availability, continuity and timeliness of remote-sensing data as well as assured access to the data at a reasonable cost are among the factors that determine the benefits to be derived from remote sensing and its widespread incorporation into Earth information systems and decision-making processes. To date, such user-friendly and low-cost operational satellite systems which could provide such services or stimulate a sustained development in this direction are not yet in place.

C. Analog and digital image processing and photo-interpretation

26. The availability of multispectral aerial and satellite imagery has led to the development of new techniques for both image processing and photo-interpretation. While the human eye can differentiate only some 15 to 25 grey levels, it may distinguish thousands of shades of colours and hues. Multichannel projectors (additive colour viewer) such as the MSP-4 Multispectral Projector allow the superposition of information contained in multispectral imagery in a way suitable for visual (analog) image interpretation. Such instruments also permit analog image processing and contrast enhancement such as the addition, subtraction and ratio of different spectral bands of the same image, which otherwise would require arithmetic operations by means of computers using digital remote-sensing data. However, digital image processing is more versatile, quantifiable and objective.

27. Image enhancement is the deliberate modification of an image in order to highlight selected spectral, radiometric and/or spatial features or areas on it. Multispectral classification is an information extraction process that analyses the spectral properties of data and then assigns each pixel to different classes on the basis of similar spectral signatures. This classification may be either supervised or unsupervised, depending on whether the assignment to a class is based on spectral signatures determined for real reference (calibrated) objects within the scene or whether it differentiates the scene only on the basis of predetermined spectral parameters (i.e., in the spectral domain only). More advanced classification techniques include those known as cluster analysis of the minimum-distance type, the maximum likelihood techniques and classification techniques using potential functions.

28. The availability of digital multispectral data from the LANDSAT programme accelerated the development and use of digital image processing in the mid-1970s. Computer-aided automatic or interactive image processing and analysis is becoming universal although its data products are still predominantly aimed at image enhancement and rectification, i.e., at providing optimal data presentations for visual interpretation. In addition, statistical analysis and classification of features as well as corrections made on the basis of multisource data are more common. Image restoration processes recognize and compensate for data errors, noise and geometric distortion introduced by atmospheric effects, the scanning process, data transmission and reception.

29. Digital image processing of photographs requires the conversion of different image tones into different electrical signals that are subsequently digitalized. A broad variety of devices such as flat-bed scanners, drum scanners, laser-beam and television-scanning devices of different spatial and densitometric resolution is available today. Two systems manufactured in the German Democratic Republic (FEAG-200 Photoscan and Photowrite System) were demonstrated during the course. Participants were also introduced to other instruments, both analog and digital, which could be used for image processing, viewing, map and image analysis; these include the Mini-BVS work station and other equipment manufactured by ROBOTRON and VEB Carl Zeiss Jena of the German Democratic Republic.

30. Photo-interpretation of remote-sensing images is still the predominant use for such data in geology. In this very interactive interpretation process, the data are combined with information from other sources such as topographic and geologic maps, statistics and filed data. An experienced photo-interpreter will identify features in the images chiefly by looking for differences or similarities in shape, size, pattern, structure, texture, topographic location, colour and tone. Their interpretation requires thorough knowledge of feature-context-cause relationships and of respective interpretation models.

D. Spectral response of surface objects in the visible, infrared and microwave range

31. In the visible, near and thermal infrared ranges of the electromagnetic spectrum, there are several pronounced absorption bands for iron as well as for various minerals (especially clay minerals) and rocks. High spectral resolution in these spectral bands are therefore of promise in differentiating between various types of soils as well as between unaltered and altered (hydrothermally mineralized or weathered) rocks. However, the spectral resolutions required (about 1.5 nm) for detailed geochemical analysis or for mineral and rock discrimination (better than 40-100 nm) are not yet available on an operational and imaging basis.

32. Electromagnetic radiation observed in the visible and near infrared bands consists of reflected or back-scattered solar radiation, while thermal infrared energy, which is generally recorded in the two main atmospheric "windows" centred around 7 μm and 5 μm as well as in the 8-12.5 μm region, is emitted by the elements of the Earth's surface. The radiant emittance of an object depends on its temperature and emissive properties. The emissivity of an object is the ratio between its real radiant emittance and that of a black body of the same temperature. The emissivity of magmatic rocks shows a minimum in the wave-length range between 8.5 μm and 11 μm with a shift to longer wavelength as the mineral content of the rocks becomes higher. Nevertheless, this potential for discrimination cannot yet be exploited to the limited spectral radiometric resolution of thermal infrared sensors and owing to the fact that the emitted energy in this spectral range varies strongly with temperature.

33. Surface temperature is a carrier of geological information. However, it is influenced by many factors related to the sun, wind speed, air temperature, surface roughness, surface colour, humidity and plant cover. Geological information from

the deeper crust is brought to the surface by geothermal heat flux. While daytime temperature variations of the Earth's surface are rather noisy, with only a relatively small signal of geological relevance, repetitive observations during the night yield information about differences in thermal inertia of the material of the upper soil/rock layer. The thermal inertia of an object depends on its moisture content, porosity and density. Analysis based on this property has been used successfully only on an experimental basis. Thus, the analysis of thermal infrared images is often combined with the use of images in the visible range.

34. The application of thermal infrared sensing in geology is especially promising in the following areas: (a) localization and monitoring of thermal anomalies connected with volcanic and geothermal activity and exploration of geothermal energy; (b) localization of temperature anomalies in connection with uranium and sulphuric ore exploration; (c) lithological mapping; (d) regional structural mapping; and (e) geological and geophysical engineering investigations.

35. While clouds and fog are practically opaque to electromagnetic waves in the visible and infrared range, they are transparent to microwaves in the centimetre and decimetre ranges. The microwave emissivity, reflectivity and penetration depth (skin-depth) properties of an object are mainly determined by its complex dielectric constant and thus by its electrical conductivity. Since small amounts of water in soils and rocks change their electrical conductivity drastically, the quantitative estimate of moisture content in soils and vegetation cover is one of the most attractive applications of passive microwave remote sensing. The apparent radiometric temperature and the reflectivity of objects observed in the microwave range depend, additionally, on the type(s) of material within the skin-depth and on the wavelength, polarization and angle of observation of the microwave radiation. To date no theory which takes all these parameters into consideration has been developed. Comprehensive collection of ground control is thus indispensable for the proper interpretation of both passive and active microwave (imaging radar) data.

36. The strong influence of the texture of objects on the back-scattered radar energy can be of great help in identifying soil and rock types and vegetation cover, but this effect can be fully exploited only when measurements at different frequencies are available. This is not yet the case in most operational systems. A field experiment carried out by the Jet Propulsion Laboratory (United States of America), in Death Valley, where a great diversity of scales in surface roughness exists (salt deposits, sand, gravel, dunes, bad lands, erosion features), has clearly demonstrated the potential of radar for separating various classes of objects according to their differences in surface roughness. A comparison between theoretical predictions and observed differences in radar brightness for these various classes showed good agreement in more than 70 per cent of the cases. Thus, surface elements which were not discernible on the basis of their colour and brightness in visible and near infrared images could be clearly differentiated on the basis of radar data.

37. One main advantage of radar imagery for applications in geology is its low viewing angle (especially in the case of SLAR). Even subtle geomorphologic-structural features are strongly emphasized as a result of radar shadows. Another benefit is the elimination of the screening effect of vegetation,

which in conventional black and white photography masks details in rocks at the surface and in the topography. Radar imagery also enhances the photographic contrast between unconsolidated geologic units and bedrock. Alluvium, lacustrine deposits, landslide debris and similar units appear dark in tone and contrast sharply with more consolidated units. Different kinds of bedrock units, however, are indistinguishable on the radar imagery except where such units engender a characteristic form of topographic expression.

38. Radar imagery is particularly suitable for the detection of faults and other linear geomorphological features. They are most clearly visible when being illuminated by the radar beam perpendicular to their strike. Although radar shadowing causes some loss of information, about 70 per cent of linear features may be discernible in a one-side-look image as compared to about 90 per cent in the case of a dual-look image. A combination of radar and multispectral satellite imagery has the additional advantage of compensating for the loss of information in the radar shadows and of combining the benefits of multispectral and detailed relief information.

E. Problem-oriented interpretation of satellite images for geological purposes

39. One of the key elements in geological interpretation of remote-sensing imagery is the identification, characterization and classification of photo-lineations. They may be related to ground features of different origin and surface expression such as linear depressions, fractures or joint zones, boundaries of soil types, lithological borders and bedding trends. Classifications of photo-lineations should take into account the area under investigation, their length, direction, frequency and density, their morphology (negative, positive, drainage-related), structural type (simple, complex) and their detailed internal structure and contrasts in tone.

40. Lineaments are more frequent in areas of outcropping basement rocks than in those with platform covers. Drainage patterns indicate fault systems, watershed positions, morphology and differences in rock type and permeability. Although the main genetic types of faults (dip-slip, transcurrent and upthrust faults) tend to show some systematic differences in general surface appearance, their discrimination in satellite imagery is not yet satisfactory. Only 5-10 per cent of the lineaments identified in such imagery can be generically classified, with the proper identification of thrust faults being the most difficult. One obtains a higher percentage of accurate identification of fault types when working with aircraft images.

41. The interpretation of satellite images for geological problems may be approached in a variety of ways. One of these is to obtain more complete information about an object of interest by a combined analysis of many different types of images and independent contextual information. Another possibility is to learn more about the connection between superficial image features and deep-seated structures and causes. Neo-tectonic block movements often result in a higher frequency of photo-lineations. The distance relationships between them yield

information on their depth extension, vertical "amplitude" and horizontal scale. They are positively correlated, thus allowing image interpretation at various levels. A third approach is to decipher the historical development of a section of the Earth from recent manifestations of patterns of image features and their mutual relationships. The off-setting or cross-cutting of older fractures, dykes, folds or rock units by younger ones is a typical example which allows the inference of relative age differences. Finally, information about geochemistry and/or mineralogy can be extracted within the limitations discussed in paragraphs 31 and 32 above.

F. Role of remote sensing in assessing geological hazards

42. One of the main applications of geological interpretation of remote-sensing imagery and other data derived from space techniques (e.g., on recent crustal movements) is to study recent and ongoing geological processes in order to assess geological hazards. The latter are diverse (such as earthquakes, landslides, and volcanic eruptions) and are often intricately interrelated. The Armenia earthquake of December 1988 in its regional seismo-tectonic context served as a case study in assessing the potential of occurrence of strong crustal earthquakes.

43. The first step in evaluating a geological hazard is to study the Neogene-Quaternary evolution of the territory of interest. Recent geological structures such as scarps, narrow depressions, linear zones of abundant watering or peculiar vegetation often appear more pronounced than ancient geological structures in satellite images. Areas of concentrated occurrence of recent crustal deformations are considered to be of potential seismic risk although not all recent structures, and faults in particular, have retained their high activity. Thus it is important to determine the trend of neo-tectonic evolution of the region under study by determining whether movements in any specific place have accelerated or slowed down, and whether any restructuring has occurred. Space photography from south-western Syria revealed two major neo-tectonic elements of a northern and north-eastern trend. According to geological data of the Pliocene-Quarternary age, the former direction cuts across the latter and older direction (active until the Miocene period) in a right-lateral sense. Consequently the north-trend structures pose a greater seismic hazard.

44. In order to distinguish and map active faults, aerial and space images of different scales and types have to be evaluated. Images taken in the near infrared are especially useful for the analysis of fine relief features and are also very sensitive to variations in vegetation, which is sometimes even more indicative of Holocene activity of faults than changes in topography. SLAR images emphasize topography and help to make visible even subtle differences in elevation. In other areas, thermal infrared airborne images may be particularly useful in detecting soil moisture related to active fault zones. Lateral strike slipping of faults may be indicated by consistent curving of river valleys and gullies or by horizontal off-setting of alluvial fans with respect to their feeding valleys. Normal dip-slip or thrusting of faults are indicated, instead, by geomorphological scarps, variations in the depth of the fault-line cut in the terrain, the splitting of terraces and variations in their height. The recognition of these features requires high-resolution stereoscopic images.

45. Information derived through remote sensing can play only a complementary role in the required complex assessment of geological hazards. This information has to be evaluated together with the results of independent geological, geophysical, geochemical, geodetic and landscape observations, and repeated surveys are indispensable. This also applies to the monitoring of slow changes, such as creeping disasters, which are connected with the advance of erosion or sedimentation, desertification, salinization or to developing swamps due to alterations in the coastlines of seas and lakes and other geologically induced changes in the landscape.

G. Application of remote sensing for prospection of mineral deposits

46. The potential contributions of remote sensing to the exploration of both vein mineralization and strata-bound potash and salt deposits in the southern part of the German Democratic Republic were demonstrated by means of case studies conducted in the Thuringian Forest, the Harz Mountains, the Vogtland and the Eastern Erzgebirge. Emphasis was placed on identifying surface expressions of hydrothermal veins under conditions of humid climate and intense cultivation, i.e., of an anthropogenetically heavily overprinted Earth's surface.

47. Vein mineralizations are bound to late Mesozoic uplifted blocks and genetically related to late Hercynian magmatism. In some cases they are also related to Permian volcanic activities as well as to a regional mobilization and circulation process generated by vertical block movements but without a clearly defined relation to magmatic activities. In case of the Vogtland mineralizations and their relationship to the regional water circulation régime (manifested in numerous mineral springs), a possible connection with local swarm earthquake activity was discussed in terms of natural liquid-induced seismicity.

48. Remote-sensing interpretations related to the exploration of mineral deposits in the German Democratic Republic were based mainly on Soviet KATE-200 and LANDSAT images, complemented by data from aerial photography (both high-flying aircraft and low-flying helicopter) and SLAR missions as well as ground-based field spectrometer measurements. These data, together with additional independent geoscientific results, were used to complement available knowledge about local and regional fault patterns and their mutual relationships, thereby yielding fresh insights into already known mineralizations, their genesis and their wider potential. The remote-sensing interpretations and inferences made by the participants were checked during field exercises in the training areas (see paras. 58-61 below).

49. The major conclusions derived by the participants from these exercises were as follows: (a) the circulation of hydrothermal solutions is mainly controlled by the less mineralized principal faults; (b) the vein structures in the inner parts of block segments owe their mineralization to water circulation; (c) the photolineations identified in the remote-sensing data were dominated by morphological structures (mostly negative forms), water circulation (lower spectral reflectance), zones of hydrothermal alteration (higher spectral reflectance) and off-sets of morphological magmatic veins and quartz zones sticking parallel to the fluorine spar vein structures; (d) the relative temporal succession of the tectonic

elements could be determined by the criteria of cross-cutting faults; (e) the best results were achieved where remote-sensing data could be complemented by independent, detailed data from geophysical and pedo-geochemical mapping and by other geoscientific primary data; and (f) the combined analysis of various data sources maximizes information output, minimizes prospecting costs and leads to optimal selection of areas for detailed studies.

H. Remote-sensing applications in hydrogeology and water resources surveys

50. The use of remote sensing in hydrogeology is complicated by the fact that ground water is not visible in the images; thus, indirect inferences have to be drawn from surface features. Hydrogeological applications are further impeded by humid climate, dense vegetation cover and anthropogenetic features. In developing countries the lack of detailed information is the main limiting factor.

51. During the past few decades, new remote-sensing techniques such as multispectral imaging in the visible spectrum, the near and far infrared range as well as in the microwave range (radar) have made it possible to successfully solve many hydrogeological problems. Satellite airborne imagery is interpreted to show the prevailing rock types and potential aquifers. Drainage patterns provide information on the permeability of aquifers; repeated observation is indispensable in regions where drainage patterns change seasonally. In hydrogeological applications, geo-botanical information can be very useful. Particularly in semi-arid regions, the density of vegetation cover often reflects the amount of moisture in the weathered zone as well as the quality of water; it also provides insights into the tectonic features. As compared to conventional ground-based hydrogeological mapping, the survey time and cost for comparable map scales can be reduced by about 20-50 per cent by incorporating remote-sensing data.

52. In densely vegetated areas, relative changes in the ground water level may be estimated from the leaf reflectivity and height of the canopy of the considered plant species. Ground-water pollution (e.g. by oil substances, heavy metals, cyanides and nitrogen compounds) affects leaf and canopy reflectance, particularly in the near infrared spectral range; thus, the degree and spread of water pollution may be detected and monitored.

53. Through remote sensing in different spectral ranges it is possible to determine more accurately, in less time and at a smaller cost, several parameters of the water budget, such as infiltration, run-off evapo-transpiration, soil humidity (although only in the uppermost tens of centimetres of the soil profile) as well as the location and quantity of inflow of ground water to surface flow. Because of the unique spectral signature of water, remote-sensing imagery in the visible or near-infrared is also particularly well suited for mapping and inventory of surface water bodies (lakes, ponds and fluvial environments). Repetitive observation of watershed areas can also play an important role in predicting water run-off during flood régimes and annual water availability, and thus contribute to improved planning of water exploitation, river navigation, management of water storage and discharge of dams for hydroelectric power and irrigation schemes.

Remote sensing is also a powerful tool for monitoring water temperature and quality (e.g., water transparency, amount of suspended material, chlorophyll) or pollutants. All these factors were extensively discussed on the basis of a case study in West Africa.

I. Application of remote sensing to the study of arid and semi-arid lands

54. As a result of inaccessibility or climatic conditions adverse to man, it is often difficult to obtain needed geological and other environmental or cartographic data from arid or semi-arid lands by conventional methods. Therefore, repetitive and synoptic remote-sensing data, mainly from satellites, are of greatest value for quick investigation of these regions, for preparing resource inventories, monitoring delicate environmental changes such as progressive desertification and salination of soils, assessing the grazing capacity of sparsely vegetated pasture areas as well as for geologic-tectonic, geomorphological and soil mapping. The potential of remote sensing for carrying out surveys was illustrated by means of various case studies carried out in China and the Islamic Republic of Iran.

J. Application of mathematical methods in remote sensing

55. Two presentations were dedicated to the evaluation of multivariate data. Starting from general consideration with regard to the existence, generation and use of multidimensional features in geosciences, algorithms for decision-making were presented and demonstrated through simple examples.

56. The concept of unsupervised versus supervised classification was presented and demonstrated for the case of digital image processing. Particular attention was paid to the practical application of these algorithms under real conditions. With this aim, a presentation was given on two procedures used at the Central Institute for Physics of the Earth of the Academy of Sciences of the German Democratic Republic. These procedures allow the interactive optimization of classifiers, the computer-aided quality control of the classification results and the possibility to combine different algorithms.

57. The participants had the opportunity to familiarize themselves with the use of these algorithms. Additionally, representatives of VEB ROBOTRON demonstrated a personal computer-supported digital image processing system (Mini-BVS work station). Because of their relevance to geological applications, special emphasis was placed on algorithms for texture and pattern recognition and classification. These algorithms were demonstrated on aerial photography from the Schirmacher Oasis, Antarctica and on radar images from Venus.

K. Field exercises in training areas

58. The lectures and classroom exercises were complemented by six days of field exercises in different training areas (Vogtland region, Eastern Erzgebirge and Sub-Hercynian basin/Harz border fault). Their main aim was to verify the inferences drawn from the interpretation of various types of remote-sensing imagery made during the course and from spectral signature measurements obtained under humid climate conditions.

59. In training area No. 1 (Vogtland) the following questions were discussed and related features demonstrated: (a) representation and characteristic features of the granite massif of Vergen as it affected land use patterns and morphological features seen in remote-sensing imagery; (b) geology of the characteristics of rocks; (c) thematic interpretation of fold structures and of hilly terrain caused by diabasic monadnocks; and (d) interpretation of data based on remote sensing, geomorphology, geology and seismology in order to reveal relationships between tectonics, deformation features and local earthquakes.

60. In training area No. 2 (Eastern Erzgebirge) emphasis was placed on remote-sensing applications to geological prospecting and to the exploration of fluorite and baryte vein mineralizations. This was illustrated through a two-stage interpretation process. In the first stage, regional fault patterns were analysed using image scales of 1:100,000, while in the second stage, the mineralized fault structures were investigated in detail using images at scales of 1:25,000 and 1:10,000.

61. The final field exercise in the Sub-Hercynian basin and the Harz Mountains aimed mainly to illustrate: (a) the detection of different rock types and faults along the northern border fault zone of the Harz Mountains; (b) ground verification of the spectral characteristics of rock types by means of field spectrometer measurements; (c) field checking of fault zones characterized as linear zones of increased moisture content; (d) pattern recognition as a tool for rock discrimination; and (e) demonstration of the kinematic aspects of block tectonics under the uplifting conditions of the Harz block.

II. COURSE EVALUATION

62. At the conclusion of the course, participants were asked to complete a questionnaire on the different aspects of the course and the usefulness of the various topics covered and field exercises carried out. The answers and comments by the participants regarding the questionnaire were evaluated and discussed with them at a final meeting.

63. All participants assessed the training course positively. They rated as most useful those exercises devoted to a specific application, such as mineral exploration or hydrogeology. The participants expressed the opinion that in the future more time should be allocated to computer-assisted interpretation procedures.

Annex

PROGRAMME OF THE COURSE

Date	Time	Subject	Speaker
Friday 6 October	9-10 a.m.	Opening ceremony	
		Welcome address on behalf of the United Nations	H. J. Haubold (United Nations)
		Welcome address on behalf of the Academy of Sciences of the German Democratic Republic	H. Kautzleben (German Democratic Republic)
		Welcome address on behalf of the Central Institute for Physics of the Earth	E. Hurtig (German Democratic Republic)
	10.15-noon	Geology and remote sensing	P. Bankwitz (German Democratic Republic)
	1-2.45 p.m.	Fundamentals of remote sensing	P. Bormann (German Democratic Republic)
	3-4.15 p.m.	Remote sensing: current and future trends	P. Bormann (German Democratic Republic)
	4.15-5.45 p.m.	Contribution of remote sensing to regional seismo-tectonic hazards: case study of the Armenia earthquake of 7 December 1988	V. G. Trifonov (USSR)
Saturday 7 October	9-10.15 a.m.	Radar applications to geology	M. Graniczny (Poland)
	10.30 a.m.-noon	Seismic hazards and remote sensing	V. G. Trifonov (USSR)
	1-3 p.m.	Applications of space techniques in neo-tectonic studies	V. I. Makarov (USSR)
	3.15-5 p.m.	Applications of remote sensing in hydrology	Z. Hrkal (Czechoslovakia)

Date	Time	Subject	Speaker
Sunday 8 October	9-10.15 a.m.	Exercise on geological evaluation of radar imagery	M. Graniczny (Poland)
	10.30 a.m.-noon	Geological interpretation of satellite data	P. Bankwitz (German Democratic Republic)
	Afternoon	Transfer to the Vogtland region: training area No. 1	
Monday 9 October		Field exercises in the Vogtland region: training area No. 1	H. Kämpf, J. Pilarski (German Democratic Republic)
	Evening lecture	Geomorphology and neo-tectonics	J. Pilarski (German Democratic Republic)
Tuesday 10 October		Field exercises in the Vogtland region: training area No. 1	H. Kämpf, J. Pilarski (German Democratic Republic)
Wednesday 11 October		Departure for Jena	
	11 a.m.-12.30 p.m.	Visit to the Carl Zeiss Jena Application Centre	K. Szangolies (German Democratic Republic)
	Afternoon	Transfer to the Eastern Erzgebirge: training area No. 2	
Thursday 12 October		Field exercises in the Eastern Erzgebirge: training area No. 2	H.-U. Wetzel (German Democratic Republic)
	Evening lecture	Remote sensing aided water prospecting in India (case study and discussion)	Ajay Sing Rajawat (India)
Friday 13 October		Field exercises in the Eastern Erzgebirge: training area No. 2	H.-U. Wetzel (German Democratic Republic)

Date	Time	Subject	Speaker
Saturday 14 October	9.30-10.45 a.m.	Analog optical image processing	V. Kroitzsch (German Democratic Republic)
	11 a.m.-12.15 p.m.	Mathematical methods and digital space image processing	J. Harff, G. Schilbach (German Democratic Republic)
	2-2.45 p.m.	Presentation of a Mini-BVS work station	Delegation from VEB ROBOTRON (German Democratic Republic)
	3-4 p.m.	Exercise in mathematical methods and digital space image processing	J. Harff, G. Schilbach (German Democratic Republic)
Sunday 15 October		Excursion to Berlin	
Monday 16 October	8.30-10.30 a.m.	Methods of image interpretation for geological applications (exercises)	P. Bankwitz (German Democratic Republic)
	10.45-11.45 a.m.	Image texture analyses	S. Röser (German Democratic Republic)
Tuesday 17 October	8.30-9.45 a.m.	Digital processing of images	H. Wirth (German Democratic Republic)
	10-11.45 a.m.	Infrared analyses	A. Gebhardt (German Democratic Republic)
	1.30-3.30 p.m.	Remote-sensing applications in water resources: case studies in West Africa	E. Zilioli (Italy)
	4-6 p.m.	Exercise on remote-sensing applications in water resources	E. Zilioli (Italy)

Date	Time	Subject	Speaker
Wednesday 18 October	8.30-9.45 a.m.	Applications of remote sensing to the study of arid and semi-arid lands	T. Woldai (Netherlands)
	10 a.m.-noon	Exercises in applications of remote sensing to the study of arid and semi-arid lands	T. Woldai (Netherlands)
	1.30-2.45 p.m.	Geological exercise	P. Bankwitz (German Democratic Republic)
	3 p.m.	Departure to Harz Mountains: training area No. 3	
Thursday 19 October		Field exercises in the Sub-Hercynian basin and Harz Mountains: training area No. 3	H.-J. Franzke (German Democratic Republic)
Friday 20 October		Continuation of field exercises in training area No. 3	H.-J. Franzke (German Democratic Republic)
Saturday 21 October	9-10 a.m.	Geochemistry and remote sensing	K. Hahne (German Democratic Republic)
	10.15-11.15 a.m.	Remote sensing and geological models	P. Bankwitz (German Democratic Republic)
	2-4 p.m.	Final discussion	P. Bankwitz (German Democratic Republic)
Sunday 22 October	9 a.m.-4.30 p.m.	Excursion to Wittenberg	
	6-9 p.m.	Closing ceremony; presentation of certificates	E. Hurtig (German Democratic Republic) H. J. Haubold (United Nations)

UNITED NATIONS

A

General Assembly

Distr.
GENERAL

A/AC.105/442
6 February 1990

ORIGINAL: ENGLISH

COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

REPORT ON THE FOURTEENTH UNITED NATIONS/FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS INTERNATIONAL TRAINING COURSE ON THE APPLICATIONS OF REMOTE SENSING TO LAND RESOURCES, HELD IN CO-OPERATION WITH THE GOVERNMENT OF ITALY

(Rome, 6-24 November 1989)

CONTENTS

	Paragraphs	Page
INTRODUCTION	1 - 8	2
A. Background and objective of the course	1 - 4	2
B. Organization of the course	5 - 8	2
I. SUMMARY OF THE COURSE	9 - 42	3
A. Fundamentals of remote sensing	9 - 17	3
B. Photointerpretation of land resources	18 - 27	5
C. Digital image processing and information systems	28 - 35	7
D. Applications of meteorological satellite data	36 - 38	9
E. Applications of thermal infrared and radar data	39 - 40	9
F. Presentations by participants and field-work	41 - 42	10
Annex. Programme of the course		11

INTRODUCTION

A. Background and objective of the course

1. The present report covers the fourteenth course in a series of courses jointly organized by the United Nations (through its Programme on Space Applications) and the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the Government of Italy, and held at FAO headquarters in Rome. The purpose of these courses is to train and assist people from developing countries to make the most effective use of remote sensing data. The course series, which began in 1976, has provided education and practical training to participants from developing countries in the use of aerial and satellite imagery for crop statistics and agricultural census, forestry, pasture and range-land development, thematic mapping, fisheries, hydrology, water resources and aquaculture.

2. The fourteenth course was part of the activities of the United Nations Programme on Space Applications for 1989 and was devoted to applications of remote sensing to land resources. The course was jointly organized by the United Nations and FAO in co-operation with the Government of Italy and was held in Rome from 6 to 24 November 1989.

3. The present report has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Sub-Committee. The participants will report on the course to the appropriate authorities in their countries.

4. The participants expressed their appreciation to the United Nations, FAO and the Government of Italy for organizing and hosting the course, for their financial assistance and for the technical quality of the course.

B. Organization of the course

5. Invitations to nominate candidates for the training course were sent by the United Nations and FAO to the developing countries through United Nations Development Programme (UNDP) and FAO representatives. Twenty-three participants, jointly selected by the United Nations and FAO, attended the course, coming from the following 22 countries: Brazil, Burundi, China, Egypt, Ghana, India, Indonesia, Kenya, Lebanon, Liberia, Mexico, Mongolia, Nepal, Nigeria, Peru, Sierra Leone, Sudan, Syrian Arab Republic, Thailand, Tunisia, United Republic of Tanzania and Viet Nam. The participants were senior technical personnel active in or responsible for agricultural development or other land resource management activities in their countries. Instruction was provided by experts from Italy, the Netherlands, Sweden, FAO, the World Health Organization (WHO), the European Space Agency (ESA) and the United Nations (Outer Space Affairs Division).

6. Funds allocated by the United Nations and FAO were used to cover the cost of international air travel for the 23 participants, and the Government of Italy provided fellowships to cover subsistence expenses. The general organization of the course and the technical programme were jointly planned by the United Nations

and FAO. The United Nations received and processed the applications for participation in the course. FAO co-ordinated the local arrangements and provided the technical equipment, materials, course facilities and local transportation in Rome. The course programme, including a list of the technical papers presented, is contained in the annex to the present report.

7. The course was opened by Dr. Mohamed S. Zehni on behalf of FAO and Mr. Ralph Chipman on behalf of the United Nations.

8. The lectures covered the following topics: fundamentals of remote sensing of land resources, including the characteristics of airborne and satellite imagery; principles of radiometry and spectral properties of natural materials; photo-interpretation theory and practice; principles of digital image analysis; drainage and land form analysis; thermal infrared and radar mapping of land resources; applications of meteorological satellites for mapping vegetation; land use mapping; identification of risk areas for water-borne diseases; geographic information systems; integration of remote sensing into resource management; and cost/benefit considerations. The participants were also provided training in the use of stereoscopes and other basic interpretation equipment and were introduced to the use of digital image processing systems. In addition, a number of practical exercises and workshops on selected topics were undertaken, both in the classroom and during field work in selected areas south and east of Rome. A summary of the course lectures is presented below.

I. SUMMARY OF THE COURSE

A. Fundamentals of remote sensing

9. The development of remote sensing applications requires a knowledge of the scientific principles underlying remote sensing, including the propagation of electromagnetic radiation through the atmosphere, the interaction of radiation with matter, the detection of radiation by detectors and the generation of images in photographic or electronic form. The sensors themselves are classified as imaging or non-imaging depending on whether the sensor data can be converted into a map-like representation of the scene observed. Remote sensing deals primarily with imaging sensors. Sensor systems are also classified as active or passive systems depending on whether they supply their own source of radiation, as in the case of radar, or use natural radiation, as in the case of photographic systems.

10. Airborne photographic cameras are still the most commonly used remote sensing systems. The advantages offered by aerial photography include geometric accuracy, stereoscopic relief information, a broad range of image scale and coverage depending on the flight altitude and camera focal length, a broad choice of film-filter combinations to select spectral bands, well-established procedures for acquiring and interpreting images, a large number of experienced photo-interpreters and photogrammetrists and the flexibility of acquiring images at the desired time and place.

11. Photographic systems are sensitive to the visible portion of the electromagnetic spectrum and to portions in the ultraviolet and near infrared regions. Because shorter wavelength radiation is scattered more by the atmosphere, resulting in hazy images, the ultraviolet band is not commonly used for remote sensing purposes, and blue light is often excluded in favour of near infrared radiation. The selection of photographic spectral bands, through the selection of films and filters, is determined by the colours or spectral bands that best distinguish the objects to be studied. The use of colour infrared film with filters to eliminate blue light, for example, is used to study vegetation since green leaves are highly reflective in the near infrared and that reflectance is sensitive to vegetation type and condition.

12. Although aerial photographs may be obtained with any type of camera, because most photographs are taken for mapping purposes, specialized cameras with precise geometries are usually used. Aerial photographs are generally taken looking vertically downward and in rapid succession on a large format film, usually 23 cm by 23 cm. The focal length and the altitude of the aircraft determine the scale of the photograph and the surface area covered. Stereoscopic relief information is provided by taking successive photographs with 60 per cent overlap, thereby ensuring that all areas on the ground are viewed from different angles on successive images.

13. The information obtained from aerial or space photography is generally used to create a map or is transferred onto a map. This can be done either by tracing features from the photograph onto a transparent overlay, by visually comparing features of the photograph with corresponding features on a map and transferring information free-hand or by using equipment that optically superimposes the photographic image on the map.

14. Photo-interpretation involves the identification and evaluation of features on a photograph that are considered significant for some purpose. The photographic elements on which the identification and evaluation are based are the size, shape, tone and colour, texture, pattern, shadow, site and association of the various features on the photograph.

15. Visual interpretation of satellite imagery is an extension of photo-interpretation of aerial photography, differing mainly in that the small scale of the satellite imagery and the lack of stereoscopy make features less easily recognizable. While an untrained viewer can recognize many common features, such as trees, rows of crops, buildings, roads and animals, on a large-scale aerial photograph these features are generally too small to be seen on satellite imagery, and few untrained viewers can reliably interpret the larger features. Information must often be deduced from seemingly abstract textures, patterns and associations. Satellite image interpretation, therefore, tends to be more theoretical and more specialized than photo-interpretation. The repetitive nature of satellite data is often useful in interpretation since images from different seasons or years will show changes that indicate the nature of the area.

16. The information gathered by a sensor in each spectral band can be converted into a black-and-white image. Alternatively, three bands can be combined by superimposing a red image of one band, a green image of a second, and a blue image of a third to give a colour image. Since most satellite colour images combine an infrared image with visible-light images, the tones and colours of the image are not the real colours of the objects, but false colours, the significance of which must be learned. A knowledge of the spectral properties of various targets, such as water, vegetation and soil, in the spectral bands combined in the image, can then be used, along with textures and patterns, in the interpretation of the image.

17. The variations in tone and colour in an image are seen as textures and patterns, which reflect variations in topography, plant cover, drainage network, soil type, geologic structure and land use patterns. Analysis of these features can provide information useful for such applications as agricultural planning, water resource development and land use management. This information can then be used for evaluating possible decisions relating to resource development and management.

B. Photo-interpretation of land resources

18. In analysing a remote sensing image, it is often useful to begin with the drainage system. A map of the drainage network provides information not only on the availability of water, but also on topography, land-forms, soil type and geological structure. The patterns formed by streams and rivers usually fall into one of six categories: dendritic, trellis, parallel, radial, annular and rectangular. Each of these patterns corresponds to a particular type of land-form and geological structure. The density of the network is a good indicator of soil type.

19. Parallel drainage patterns, for example, with tributaries parallel to each other and joining the mainstream at approximately the same angle, are characteristic of gently and uniformly sloping surfaces, with the direction of the mainstream possibly indicating a fault or a fracture direction. Such patterns are commonly found on young coastal plains and large volcanic flows. A high density of drainage lines indicates impervious bedrock or clay soils of low permeability. A surface with few drainage channels, on the other hand, would indicate coarse soils and permeable bedrock.

20. The drainage network and the shading due to relief are the best indicators of land-forms on satellite imagery that does not provide stereoscopic information. The drainage pattern indicates the direction and steepness of slopes, while changes in shading indicate changes in slope and the texture of shading indicates the roughness of the terrain. On the basis of these elements, an image can be divided into such categories as mountainous areas, high plateaus, foothills, alluvial fans, flood plains and coastal plains. Differences in tone and colour on an image due to vegetation or soil differences can also be used as indicators of land-forms, although the significance of particular colours and tones are usually specific to an area so it is more difficult to define general rules of interpretation.

21. Interpretation of vegetation is usually done with infrared false colour images, on which vegetation appears in various shades of red. The sensitivity of the infrared reflectance of green plants to a variety of factors means that differences in vegetation tend to show up clearly on the false colour images. Using these colour differences, it is fairly easy to interpret images in terms of general density of green vegetation and to map the boundaries between different types of vegetation. To determine the actual type of vegetation, the land-forms must be also be interpreted, and the climate and the vegetation indigenous to the area must be known.

22. Cultivated fields are generally identifiable by their geometric shapes and homogeneous colours and their location on relatively flat ground. Irregular patterns are indicative of uneven terrain. Different crops will often appear as slightly different colours, and a knowledge of the farming practices of the area may allow reasonably accurate inferences as to the specific crops. In general, however, accurate identification of crops requires ground verification.

23. The boundaries between soil types can often be interpreted using the drainage patterns, the land-forms, the vegetation patterns and other colour differences on the imagery. Some information on soil type can also be deduced from the drainage pattern and land-form and by the colour of areas of bare soil. Geological information, sometimes derived from the forms or colours of nearby mountains, may indicate the rock type from which the soil developed. Specific identification of soils, however, requires more knowledge of the area in question and should always be verified by spot checks on the ground.

24. Soil moisture conditions are often difficult to interpret from remote sensing data, but under some conditions information can be obtained. In arid or semi-arid regions, during dry periods, areas of subsurface moisture will appear as red areas on an image due to the green vegetation they support. In more humid areas, bare or partially bare soil will generally appear dark when the surface is wet, due, for example, to a shallow water-table.

25. Water is relatively transparent to visible light, especially blue and green light, and is quite opaque to infrared radiation. Since land surfaces, particularly those covered with vegetation, reflect fairly strongly in the infrared, false-colour or single band infrared images generally allow a clear delimitation of land and water, with water surfaces appearing as uniformly black in the infrared band. When information on depth or turbidity of water bodies is important, visible-band images offer the most information.

26. Geological features are generally directly observable only in desert areas where bare outcrops reveal the bedding, colour, fracturation and susceptibility to weathering of the rock. In most other areas, soil, vegetation cover and artificial structures cover the rock, and geological analysis is based on the interpretation of surface effects of the geologic substratum. Of the surface elements, land-forms provide the most important information about the geology of a region, with drainage patterns also providing useful information.

27. An overall procedure for interpreting satellite images for land resource information might include the following steps: (a) analysis of drainage networks and land-forms; (b) interpretation of vegetation, soils, land use and geology; (c) verification of interpretation by means of ground surveys and aerial photographs of selected areas and information from other sources; (d) compilation of information into a thematic map appropriate for decision-making, with accompanying analytical and explanatory reports.

C. Digital image processing and information systems

28. Digital processing of remote sensing imagery can serve a number of purposes, ranging from geometric transformation of the image to match a particular map format, enhancement of selected features of an image to facilitate interpretation for a particular application and computer classification of an image as a major step in the interpretation process. Since most satellite imagery is transmitted from the satellite in digital format, some digital processing must be done to put the image into the form of either a photograph or a computer tape for interpretation by the user. This basic digital processing includes standard radiometric and geometric corrections that make the image suitable for average applications. Whether additional processing is required or helpful will depend on the application and on the resources available to the user.

29. Satellite images, as provided to users, are processed to approximately match standard map scales and projections. In order to match non-standard scales or projections or to precisely match standard maps, special geometric correction may be required, using the precise geographic positions of identifiable points on the image.

30. Similarly, the processing of the radiometric characteristics of the standard images is not ideal for any particular image or particular purpose. Digital radiometric processing can increase the general contrast of the image and can eliminate features such as striping due to different responses of different detectors in the sensor.

31. In addition to relatively simple geometric and radiometric image correction, more sophisticated image enhancement techniques and high-quality photographic processing can be used to produce images that are substantially superior to standard products for visual interpretation. The most commonly used special processing techniques are precise adaptation of the image contrast and colour to the specific application and enhancement of boundaries. The digital image processing systems of the FAO Remote Sensing Centre are used primarily for this purpose.

32. More specialized digital image enhancement techniques include identification of linear orientations in the image, transformation of multiple spectral bands to maximize the information that can be recorded onto a three-band colour image, and processing band differences or band ratios. Images of the same area on different dates can be used to generate a single image showing the changes between the two

dates. All of these enhancement techniques improve the visual presentation of the image to facilitate visual interpretation, but do not create any new or additional information.

33. In addition to enhancing images for visual interpretation, digital image processing can be used as part of the interpretation process itself. Digital image interpretation, like visual interpretation, includes analysis of the tone and colour of various parts of an image in various spectral bands and classification of the image into relatively homogeneous areas. Whereas visual interpretation allows qualitative analysis of one to three spectral bands simultaneously, digital analysis allows more detailed quantitative analysis in any number of spectral bands. Digital interpretation techniques, however, are not as good as visual interpretation for texture and pattern analysis. Digital interpretation is therefore best suited to applications where spectral information is more important than texture and pattern. Digital interpretation, moreover, tends to limit the application of the experience and judgement of the specialist interpreter. Where digital analysis is appropriate, it can, with appropriate equipment, be used to process large volumes of data with uniform criteria.

34. The final output of an interpretation of remote sensing data is a thematic image or map of the area of interest. For the generation of a computer-classified image, two different classification techniques have been developed: supervised and un-supervised classification. For supervised classification, the interpreter identifies sample areas with known characteristics, and the computer classifies each element of the image according to its spectral similarity to one of the sample areas. In unsupervised classification, the computer analyses the spectral characteristics of all image elements and determines statistical groupings of elements. The interpreter must then interpret the nature of each of the groups. While supervised classification generally results in more accurate thematic maps, the objective statistical nature of the unsupervised classification may be more appropriate for certain statistical applications such as crop inventories.

35. Remote sensing can be used to make decision-making for resource management more efficient and effective. An important tool that can integrate remote sensing information with information from other sources is a geographical information system (GIS). A GIS allows data from different sources to be converted onto a common map base and permits the user to combine data in various ways in response to various management questions. An agricultural planning project, for example, might need to take into account information on soils, existing land use, administrative boundaries, topography, rainfall statistics and transportation and communication lines in order to produce a map of recommended land use. Historical data can be combined with current data to indicate trends and make future projections. While GIS systems are complex and expensive to establish, once established they can, quickly and inexpensively, produce maps with land classified according to complex criteria specifically determined for the project in question.

D. Applications of meteorological satellite data

36. For monitoring the conditions of resources that change over periods of days to months, such as crop yield or range-land carrying capacity, remote sensing data must be available frequently and reliably. While remote sensing satellites such as Landsat and Spot do not provide sufficiently frequent data to allow such monitoring, meteorological satellites can provide daily coverage. Allowing for cloud cover, good images of the ground can normally be obtained at least once a week. There is, however, a trade-off of frequency for spatial resolution since meteorological satellite images have spatial resolutions of 1 to 4 kilometres, compared with 10 to 80 metres for remote sensing satellite images.

37. The most commonly used meteorological system for vegetation monitoring is the Advanced Very High Resolution Radiometer (AVHRR) carried by the satellites of the National Oceanic and Atmospheric Administration (NOAA) of the United States of America. AVHRR provides data in five spectral bands: visible; near infrared; middle infrared; and thermal infrared (2). The difference between the reflectance in the red and near infrared bands has proved to be a particularly good estimator for green biomass. One standardized quantitative index derived from this difference is the Normalized Difference Vegetation Index (NDVI), defined as the difference between the infrared and the red bands divided by the sum of the two bands. For sparse vegetation, such as in arid or semi-arid range-land, the index is often roughly proportional to biomass. For denser vegetation, the index indicates the condition of the vegetation, but without a simple mathematical relationship.

38. In the FAO ARTEMIS (Africa Real-Time Environmental Monitoring using Imaging Satellites) programme, meteorological satellite data are being used for the detection and monitoring of potential desert locust habitats in the arid areas of Africa. Thermal infrared data from the European geostationary Meteosat satellite are used to estimate rainfall based on cloud top temperatures, taking into account the latitude and the date. Hourly observations are integrated over a period of 10 days to estimate the probable rainfall for that period. Visible and near infrared data from a NOAA AVHRR satellite, at a resolution of 4 km and integrated over a month to eliminate clouds, are used to determine the vegetation index. Computer-generated photographic maps of estimated rainfall and vegetation index are sent to the FAO desert locust control programme, where they provide an input into assessments that are sent to Governments and international organizations. The maps are also sent to the FAO Food Early Warning Programme and to a number of regional projects in Africa. These meteorological satellite data products are proving to be effective for pinpointing potential breeding habitats and allowing more rational and efficient field surveys to locate locust outbreaks and plan control operations.

E. Applications of thermal infrared and radar data

39. Radar remote sensing, using the microwave portion of the electromagnetic spectrum, offers the advantage of all-weather operation. Radar is an "active" remote sensing system in that it provides its own energy source and can obtain imagery day or night regardless of cloud cover. An imaging radar transmits pulses

of energy in a narrow beam and records the returning echoes. The time delay of the echo indicates the distance to the object, and the intensity of the return indicates the nature of the object. As the aircraft or satellite carrying the radar moves along its path, it builds up a strip of imagery covering the terrain on one or both sides to the ground track. The electronic data can be processed into the desired image format, taking into account the varying distances and angles between the radar system and the ground. The intensity of the reflection from a terrain feature depends on factors which include the texture or roughness of the surface, the slope of the ground and the moisture content of the soil or vegetation.

40. The Side-Looking Airborne Radar (SLAR), also called non-coherent or real aperture radar, is the simplest system. The resolution of a SLAR depends on the size of the radar antenna and on the distance between the radar and the target. Synthetic Aperture Radar (SAR), also called coherent radar, uses the Doppler shift of the return pulse due to the motion of the aircraft or satellite to improve the resolution of the imagery. The disadvantage of SAR is the higher cost and greater complexity of the radar and its associated data processing system. All satellite radar systems use SAR technology since SLAR technology cannot provide useful resolutions from orbital altitudes.

F. Presentations by participants and field-work

41. During the course, some of the participants made presentations on projects in which they were involved in their own countries. These presentations included applications of remote sensing to agricultural resources, soil surveys and range-land monitoring.

42. Field-work is an essential part of most remote sensing applications, and the course included two field trips to areas south and east of Rome. Imagery of the areas had been interpreted in laboratory exercises before the field trips, and particular sites had been selected for checking the interpretation. The areas included a volcanic zone with forested hills, valley bottoms and slopes with agricultural fields, interior lowlands with heavy, wet soils requiring drainage and a gently sloping sandy coastal plain. The participants compared the appearance of these areas on the ground with their appearance on false-colour images and with the laboratory interpretations.

Annex

PROGRAMME OF THE COURSE

In general, the course consisted of illustrated lectures in the morning covering theoretical and practical aspects of remote sensing applications to land resources, and workshop exercises in the afternoon in which each participant interpreted remote sensing images with respect to a particular application.

Monday, 6 November - Introduction

Registration of participants
Opening address: M. S. Zehni (FAO)
United Nations statement: R. Chipman (United Nations)
Overview of land resources appraisal and management: R. Brinkman (FAO)
Briefing on FAO facilities and course arrangements: C. Travaglia (FAO)
Overview of remote sensing: D. Kalensky (FAO)
International co-operation in remote sensing: R. Chipman (United Nations)

Tuesday, 7 November - Principles of photo-interpretation

Photo-interpretation criteria for land resources studies: P. Dainelli (Italy)
Land resources appraisal using air photo-interpretation: P. Dainelli (Italy)
Workshop on air photo-interpretation

Wednesday, 8 November - Fundamentals of remote sensing

Electromagnetic radiation and colour theory: G. M. Lechi (Italy)
Satellite systems: G. M. Lechi (Italy)
Satellite sensors: G. M. Lechi (Italy)
Workshop on multispectral imagery

Thursday, 9 November - Principles of image analysis

Principles of satellite imagery interpretation: C. Travaglia (FAO)
Introduction to digital analysis of satellite data: P. Reichert (FAO)
Introduction to FAO remote sensing facilities and services

Friday, 10 November - Drainage and land-form analysis

Drainage analysis: C. Travaglia (FAO)
Land-form analysis: P. Dainelli (Italy)
Workshop on drainage and land-form analysis

Monday, 13 November - Land-use mapping

The land system approach: M. F. Purnell (FAO)
Mapping and monitoring irrigated areas: D. P. Shrestha (Netherlands)
Workshop on mapping irrigated areas

Tuesday, 14 November - Land-use mapping

Land cover and land-use analysis: D. P. Shrestha (Netherlands)
Soil Mapping: D. P. Shrestha (Netherlands)
Workshop on land-use analysis

Wednesday, 15 November - Soil degradation

Soil degradation processes: D. P. Shrestha (Netherlands)
Interpretation of soil degradation: D. Lanatieri (FAO)
Workshop on soil degradation

Thursday, 16 November - Field trip

Field-work along Rome-Fucino route
Visit to Telespazio satellite receiving station, Fucino

Friday, 17 November - Land hazards

Flood-plain mapping: E. Zilioli (Italy)
Mapping and monitoring risks areas for water-borne diseases: R. Bos (WHO)
Workshop in preparation for field-work

Saturday, 18 November - Field trip

Field-work in the Albano volcanic zone and the Pontina Plain

Monday, 20 November - Thermal infrared remote sensing

Thermal infrared - theory and interpretation: A. Tonelli (Italy)
Estimation of soil moisture and evapotranspiration: A. Tonelli (Italy)
Thermal infrared case studies
Presentations by participants

Tuesday, 21 November - Radar remote sensing

Imaging radar - theory and interpretation: J. Lichtenegger (ESA)
Radar case studies: J. F. Dallemand (FAO)
Workshop on radar land resources mapping
Presentations by participants

Wednesday, 22 November - Agrometeorology

Rainfall estimates and vegetation index from satellite data: F. Snijders (FAO)
Meteorological satellite data for agro-ecological zoning: J. Antoine (FAO)
Workshop on vegetation index and agrometeorological applications
Presentations by participants

Thursday, 23 November - Geographic information systems

Introduction to geographic information systems: E. Ataman, J. Antoine (FAO)
Introduction to the FAO geographic information system
Remote sensing inputs to geographic information systems: Z. D. Kalensky (FAO)
Course evaluation

Friday, 24 November - Overview and closing

Remote sensing for management decision-making: S. Galli de Paratesi (Italy)
Cost/benefit considerations: Z. D. Kalensky (FAO)
Course review
Closing